EDUCATION REPORT | Genetics inMedicine

Enhancing exposure to genetics and genomics through an innovative medical school curriculum

Shweta U. Dhar, MD, MS, FACMG[1], Raye L. Alford, PhD, FACMG[2], Elizabeth A. Nelson, MD[3] and Lorraine Potocki, MD, FACMG[1]

Purpose: Physicians entering medical practice in the 21st century will require more than a basic understanding of human genetics because of rapid progress in the field of genetics and genomics. The current undergraduate medical curriculum at most institutions is not adequate to prepare medical students for these challenges. Enhancing exposure to genetics throughout the medical school curriculum should help prepare the next generation of physicians to use genetic and genomic information for optimal patient care.

Methods: We have introduced a Genetics Track Curriculum to the undergraduate medical curriculum at Baylor College of Medicine.

Results: This track runs in parallel to the existing 4-year curriculum and includes didactic sessions, small group discussions, longitudinal clinical experiences, clinical and laboratory rotations, community outreach, and scholarly projects related to genetics. It also provides the students a means to network and discuss topics and career paths in medical genetics.

Conclusion: We have developed a novel curriculum that enhances genomic education for medical students with the ultimate goal of enabling our graduates to deliver more effective and personalized medical care. We believe that the Genetics Track Curriculum at Baylor College of Medicine can serve as a prototype for other medical schools across the country and abroad.

Genet Med 2012:14(1):163–167

Key Words: genetics curriculum; genetics track; medical education; medical genetics, mentoring

IMPORTANCE OF GENETIC AND GENOMIC FLUENCY FOR THE PRACTICING PHYSICIAN

Over the past several decades, there have been countless discoveries in medical genetics and molecular biology. There has also been rapid progress in biotechnology. These advances have practical applications for the determination of disease risk, the interpretation of clinical laboratory data, the treatment of disease, the use of pharmacologic agents, and reproductive counseling.[1–4] Concomitant with the advancement of genetic knowledge and technologies is the emergence of ethical and public policy concerns related to their application to medical practice.[5,6] It is widely recognized that physicians entering medical practice in the 21st century will require more than a basic understanding of human genetics.

Historically, genetic testing has been used selectively to diagnose monogenic or chromosomal disorders or to evaluate the risk of developing or transmitting single-gene disorders. However, genetic testing is increasingly being used to modify therapeutics, to determine prognosis, and even to provide probabilistic risk assessment for common/complex disorders. Because of advances in technology and the availability of high-throughput sequencing and high-density microarrays, it is now possible to interrogate thousands of loci in an individual's genome at a relatively low cost and in a timely manner.[4,6–9] In the future, practicing physicians will need to appraise these technologies and make critical judgments and decisions regarding the results they generate for their patients. Several studies have shown that most physicians are unable to interpret even simple genetic tests, much less the complex genetic and genomic information obtained from next-generation sequencing.[10,11] Unfortunately, the current undergraduate medical curriculum at most institutions is not adequate to prepare medical students for the challenges that result from this rapidly advancing science.[12] Integrating genetics throughout the entire medical school curriculum should help prepare the next generation of physicians to use genetic and genomic information for optimal patient care.[13,14]

CURRICULAR FRAMEWORK, INFRASTRUCTURE, AND RESOURCES AT BAYLOR COLLEGE OF MEDICINE

Undergraduate medical education (UME) is traditionally divided into preclinical and clinical components. The preclinical UME at Baylor College of Medicine (BCM; http://www.bcm.edu/medschool/) spans an 18-month period and comprises eight integrated organ system blocks. Students advance to the clinical cores in January of their second year. Given the accelerated entry into clinical rotations, BCM has a shortened summer break between first and second year of only 4 weeks. BCM has seven clinical cores and a required subinternship. Students also

[1]Department of Molecular and Human Genetics, Baylor College of Medicine, Houston, Texas, USA; [2]Bobby R. Alford Department of Otolaryngology–Head and Neck Surgery, Baylor College of Medicine, Houston, Texas, USA; [3]Department of Medicine, Baylor College of Medicine, Houston, Texas, USA. Correspondence: Lorraine Potocki (lpotocki@bcm.edu.)

Submitted 12 May 2011; accepted 6 July 2011; advance online publication 26 September 2011. doi:10.1038/gim.0b013e31822dd7d4

return for longitudinal curriculum on Thursday afternoons during the second and third years. BCM has a fourth-year capstone course in the Spring that serves as a point of transition into internship.

To personalize the medical school experience, students can choose electives, pathways, tracks, or dual-degree programs. Electives may be preclinical seminars or clinical rotations. The third-year longitudinal ambulatory course has several pathways. For students interested in a specific area of medicine, BCM also offers Tracks which span all 4 years of medical school. Available Tracks include Research, Geriatrics, Care of the Underserved, International Health, Medical Ethics, Medical Management, and now Genetics. Student enrollment in the established tracks average 16% per new entering medical school class at BCM. Percent enrollment has increased for each track over time as they have gained popularity. The Genetics Track Curriculum (GTC) is comparable to these tracks in terms of time commitment and effort on the part of the medical student.

The Department of Molecular and Human Genetics (MHG) at BCM (http://www.bcm.edu/genetics/) comprises more than 75 primary and joint faculty including clinicians, clinical laboratory directors, physician scientists, and basic science researchers. In addition, the Department of MHG has accredited training programs including a medical genetics residency, combined medical genetics and pediatrics residency, postdoctoral training for board certification in molecular genetic, cytogenetic, and biochemical genetic laboratory diagnostics, a medical biochemical genetics pathway, and a PhD graduate program in molecular and human genetics. Key clinical facilities at the Texas Medical Center include the Baylor Clinic, Texas Children's Hospital, The Methodist Hospital, St. Luke's Episcopal Hospital, Ben Taub General Hospital, the Michael E. DeBakey Veterans Affairs Medical Center, and soon the new Texas Children's Maternity Center. The authors recognize that the resources at BCM and the Texas Medical Center are not universally available at most medical schools; however, most medical schools should be able to adapt a modified version of the GTC to prepare their graduates for medical practice.[13]

PROPOSAL AND IMPLEMENTATION OF A NOVEL CURRICULUM IN MEDICAL GENETICS

The 4-year GTC described herein is for medical students who want more time to explore and experience the multiple facets of basic and clinical genetics and genomics. The GTC was developed to complement the existing UME at BCM. **Table 1** lists the schedule at-a-glance for all 4 years of the GTC. In addition to the core medical school curriculum, GTC students will have the opportunity to experience state-of-the-art medical genetics diagnostic laboratories and to participate in focused didactic activities and clinical and longitudinal patient experiences. The track will also provide students opportunities for scholarly research and mentoring focused on medical genetics. The GTC incorporates well-established compulsory and elective courses for UME in addition to select courses and conferences required for graduate medical education in genetics (**Tables 1 and 2**; http://www.bcm.edu/osa/handbook/geneticstrack). Also included are multidisciplinary educational programs in genetics developed by the Department of MHG for the community ("Evenings with genetics," a community seminar series where a Genetic faculty member presents information in lay terms and an individual or parent of a child impacted by the genetic condition shares his or her unique viewpoint) and online courses relevant for human subjects research and societal implications of genetic medicine. In addition, new electives were specifically developed for the GTC some of which

Table 1 Schedule at a glance

Content	Methods	Year 1	Year 2	Year 3	Year 4
1. Didactics	Fall I—Core Concepts[a] (12 hr)	X			
	Fall II—Genetics Module[a] (22 hr)		X		
	Case-based conferences[b] (1 hr/mo; September–May)		X	X	X
	Topics in Genetics Journal Club (1 hr/mo; September–May)	X			
	Genes, Health and Society online course, "Medical Genetics and Genomics" module[b]			X	
	Human Subjects online training[b]	X	X		
2. Clinical Experience	Genetics Electives[b] (2 wk × 3) (prenatal, adult, pediatrics)			X	X
3. Medical Genetics Laboratory	McGovern Campus (2 wk)			X	X
4. Community Interface	Longitudinal patient experience	X	X	X	X
	Evenings with Genetics Seminars[b] (3/year)	X	X	X	X
5. Scholarly Project	Faculty mentor/adviser quarterly meeting	X	X	X	X
	Director semi-annual meeting	X	X	X	X
	Develop and implement scholarly project	X	X	X	X
	American College of Medical Genetics or American Society of Human Genetics annual meeting, optional			X	X
6. Enrichment	Mediaomics Book Club/Genetics in Film (optional)	X	X	X	X

[a]Existing required courses. [b]Existing electives/seminars.

will also be available for medical students who are not formally enrolled in the GTC (**Table 2**). The GTC proposal was approved by the BCM Curriculum Committee in February 2011 and opened for enrollment in August 2011.

The specific curricular elements that are employed to achieve the goals of the GTC (**Table 3**) exploit various pedagogical approaches throughout the course of the students' UME. Although the required preclinical medical genetics curriculum (Fall I Core Concepts and Fall II Genetics Module) at BCM is predominantly didactic in nature, these courses also incorporate several hours of small group facilitated discussion, some of which involve individuals diagnosed with genetic conditions. Fall I comprises a single fully integrated course called "Foundations Basic to the Science of Medicine." This course includes biochemistry, molecular and cellular biology, physiology, anatomy, histology, metabolism, radiology, endocrinology, and genetics organized into an organ system-based course. There are approximately 12 hours of genetics content woven into the course. In Fall II, the genetics content is found in a stand alone course of 22 contact hours (http://www.bcm.edu/medschool/). Other curricular elements are incorporated into the GTC to facilitate inquiry and life-long learning in genetics. These include a faculty facilitated genetics journal club, case-based conferences, online instruction, and multidisciplinary seminars on various topics designed for patients, families, educators, and allied health professionals involved in the care of individuals with genetic diagnoses. All BCM students have the opportunity to explore the practice of medical genetics in pediatric, obstetric, and adult medicine. The GTC student will be required to complete 6 weeks of electives in genetics. The patient-centered longitudinal element is unique to the GTC and begins in the first year when the student is introduced to a patient or family with a genetic diagnosis. The GTC student will also complete a 2-week rotation through the Medical Genetics Laboratories to gain an appreciation for diagnostic methods and interpretation. Concurrent with the required elements discussed above, GTC students may also participate in various peripheral yet enlightening activities including the BCM Genetics Interest Group, the Parents' Night Out community service activity for children with special needs, and the Genetics Book and Film Club (Mediaomics). Importantly, each GTC student will select a faculty mentor who will guide the student in developing and presenting a scholarly project. The GTC student will meet with the faculty mentor quarterly and with one of the GTC Directors twice per year. These meetings will foster further discussion regarding career paths and progress and inform the student about networking opportunities within BCM and nationally. Although not required, each will be encouraged to submit an abstract for presentation at a national meeting such as the

Table 2 Required elements of the genetics track curriculum

Years 1–2	• Fall I—Core Concepts (12 hr of medical genetics integrated within basic sciences) in Year 1
	• Topics in Genetics Journal Club[a] (1 hr/mo; September–May) in Year 1
	• Fall II—Genetics Module (22 hr) in Year 2
	• Attend Department of MHG Case-Based Conferences (1 hr/mo; September–May) in Year 2
	• Online Human Subjects Research Training through BCM Office of Research (complete once in Year 1 or Year 2)
Years 3–4	• Attend Department of MHG Case-Based Conferences (1 hr/mo; September–May)
	• Complete the module entitled "Medical Genetics and Genomics" in the online course Genes, Health and Society of the BCM Center for Educational Outreach (www.bioedonline.org) in Year 3
	• Pediatric Genetics Elective (2 wk; to be completed in Year 3 or Year 4) includes experiences in General Pediatric, Metabolic, and Skeletal Dysplasia Genetics Clinics and participating with the Genetics Team on inpatient consults
	• Adult Genetics Elective (2 wk; to be completed in Year 3 or Year 4) includes experiences in General Adult and Cancer Genetics Clinics and participating with the Genetics Team on inpatient consults
	• Additional Genetics Elective (Students may choose Pediatric, Adult, or Prenatal Genetics Elective; 2 wk; to be completed in Year 3 or Year 4; Prenatal elective includes experiences in the Prenatal Genetics Clinic)
	• Medical Genetics Laboratory Elective[a] (2 wk; to be completed in Year 3 or Year 4) exclusive to the Genetics Track, this elective includes experiences in the Biochemical, Cytogenetic, and Molecular divisions of the BCM Medical Genetics Laboratories, genetic counseling, and attending signout rounds, case discussion conferences, and postclinic conference
Years 1–4	• Longitudinal patient experiences[a]
	• Mentor meetings[a]
	• GTC Director meetings[a]
	• Evenings with Genetics Seminar Series (1 hr/seminar; attend 3 seminars per year)
	• Scholarly project in basic, translational, clinical, genomic, ethics, or public policy research[a]

[a]Items newly created for the GTC.

Table 3 Goals of the genetics track curriculum

1.	Build upon the foundation of basic genetic principles provided to all BCM students in the preclinical curriculum with additional educational experiences in medical genetics
2.	Enhance the medical student experience in clinical medicine to include a broad range of patients with genetic conditions
3.	Develop the medical student's appreciation for the nuances inherent in performing and interpreting clinical diagnostic analyses in biochemical and molecular genetic and cytogenetic CLIA-approved laboratories
4.	Provide an interface with the community and patient advocacy organizations to enhance the student's awareness of the social concerns faced by patients and families affected by genetic disorders
5.	Prepare the students to author a scholarly publication and/or presentation
6.	Provide the students a means to network and discuss various topics and career paths in medical genetics

annual meetings of the American College of Medical Genetics or the American Society of Human Genetics.

DISCUSSION

The practice of medicine is changing as the tools for molecular genetic diagnosis become increasingly accurate, less expensive, and readily available. The broad application of genomic medicine promises to personalize care and optimize health outcomes;[4,6,15,16] however, it seems that the medical profession is unprepared to incorporate genomic medicine into medical practice.[10,14,17,18] Perhaps, this is due to the misconception among established healthcare providers that genetics is only applicable to rare single-gene disorders or chromosomal abnormalities and hence is of concern only to specific specialties, such as pediatrics and prenatal obstetrics.[19] Or perhaps this misconception stems from the lack of integration of genetics education beyond the preclinical years of UME.[17,20] Regardless, direct-to-consumer genetic testing services have once again highlighted the need for physician education in genetics. Through various media sources, patients hear about the availability of genetic tests and approach their primary care physicians for more information or sometimes even to seek help in interpreting their genetic test results. Primary care providers need to be equipped with the knowledge to critically assess and explain genetic test results to their patients and an understanding of when and how to refer patients for specialty care in medical genetics.[21] With time, physicians of all specialties will be faced with daily challenges involving genetics and will be required to keep themselves apprised of the changes in this rapidly advancing field. Several studies have demonstrated deficiencies in physicians' knowledge about genetics and their awareness of genetic tests.[11,22–25] There have been initiatives to educate practicing physicians about genetics and genomic medicine,[26,27] yet it seems more logical that components upstream to medical practice must be modified to effect the eventual transition to personalized medical care. Hunter et al.[28] showed that a major proportion of practicing physicians rely upon their undergraduate and medical education in genetics and most physicians feel less confident about genetic counseling and testing. Over the past several decades, many studies have been published demonstrating the deficiency of genetics in the medical school curriculum,[10,18,25,29,30] and there are commentaries proposing educational reform.[10,13,17] We have developed a novel curriculum in genetics which enhances the breadth and depth of genomic education for the medical students by employing a variety of pedagogical approaches, with the ultimate goal of enabling our graduates to deliver more effective and personalized medical care. Previous reports have postulated or demonstrated that UME in genetics must extend into the clinical years to effect knowledge of and comfort in approaching patients with genetic concerns;[17,20,31] thus, we have designed the GTC to span all 4 years of the undergraduate curriculum. We anticipate that only a small percentage of each class will elect to enroll in the GTC; however, we anticipate that many more students would be willing to engage in many of the electives and/or courses that are being offered as components of the GTC. We also hope to engage not only students who are considering a career as a medical geneticist but also those who aspire to become internists, psychiatrists, and surgeons. Longitudinal analyses to explore attitudes, behaviors and career outcomes are planned for all students enrolling in the GTC and will be matched with appropriate "control" students who elect to choose different pathways. In summary, we have developed a GTC for the medical school at BCM that will incorporate medical genetics and genomics throughout the 4-year medical school experience. This track began accepting students in the Fall of 2011. We believe that exposing medical students to such a genetics track will better equip the physicians of tomorrow to practice optimal genetic care in their clinical area of expertise.

DISCLOSURE

The authors declare no conflict of interest.

REFERENCES

1. Feero WG, Guttmacher AE, Collins FS. Genomic medicine–an updated primer. *N Engl J Med* 2010;362:2001–2011.
2. Varmus H. Getting ready for gene-based medicine. *N Engl J Med* 2002; 347: 1526–1527.
3. Guttmacher AE, Collins FS. Genomic medicine–a primer. *N Engl J Med* 2002; 347: 1512–1520.
4. Mayer AN, Dimmock DP, Arca MJ, et al. A timely arrival for genomic medicine. *Genet Med* 2011;13:195–196.
5. Meslin EM, Cho MK. Research ethics in the era of personalized medicine: updating science's contract with society. *Public Health Genomics* 2010;13: 378–384.
6. Drmanac R. The advent of personal genome sequencing. *Genet Med* 2011;13: 188–190.
7. Wadman M. James Watson's genome sequenced at high speed. *Nature* 2008; 452:788.
8. Bentley DR, Balasubramanian S, Swerdlow HP, et al. Accurate whole human genome sequencing using reversible terminator chemistry. *Nature* 2008;456: 53–59.
9. Shendure J, Ji H. Next-generation DNA sequencing. *Nat Biotechnol* 2008;26:1135–1145.
10. Guttmacher AE, Porteous ME, McInerney JD. Educating health-care professionals about genetics and genomics. *Nat Rev Genet* 2007;8: 151–157.
11. Plon SE, Cooper HP, Parks B, et al. Genetic testing and cancer risk management recommendations by physicians for at-risk relatives. *Genet Med* 2011;13: 148–154.
12. Thurston VC, Wales PS, Bell MA, Torbeck L, Brokaw JJ. The current status of medical genetics instruction in US and Canadian medical schools. *Acad Med* 2007;82:441–445.
13. Nelson EA, McGuire AL. The need for medical education reform: genomics and the changing nature of health information. *Genome Med* 2010;2:18.
14. Korf BR. Genetics and genomics education: the next generation. *Genet Med* 2011;13:201–202.
15. Feero WG, Guttmacher AE, Collins FS. The genome gets personal–almost. *JAMA* 2008;299:1351–1352.
16. Kroemer HK, Meyer zu Schwabedissen HE. A piece in the puzzle of personalized medicine. *Clin Pharmacol Ther* 2010;87:19–20.
17. Korf BR. Integration of genetics into clinical teaching in medical school education. *Genet Med* 2002;4(6 Suppl):33S–38S.
18. Baars MJ, Scherpbier AJ, Schuwirth LW, et al. Deficient knowledge of genetics relevant for daily practice among medical students nearing graduation. *Genet Med* 2005;7:295–301.
19. Suther S, Goodson P. Barriers to the provision of genetic services by primary care physicians: a systematic review of the literature. *Genet Med* 2003;5:70–76.
20. Telner DE, Carroll JC, Talbot Y. Genetics education in medical school: a qualitative study exploring educational experiences and needs. *Med Teach* 2008;30: 192–198.

21. Emery J, Watson E, Rose P, Andermann A. A systematic review of the literature exploring the role of primary care in genetic services. *Fam Pract* 1999;16: 426–445.
22. Hofman KJ, Tambor ES, Chase GA, Geller G, Faden RR, Holtzman NA. Physicians' knowledge of genetics and genetic tests. *Acad Med* 1993;68:625–632.
23. Metcalfe S, Hurworth R, Newstead J, Robins R. Needs assessment study of genetics education for general practitioners in Australia. Genet Med 2002;4:71–77.
24. Burke W, Emery J. Genetics education for primary-care providers. *Nat Rev Genet* 2002;3:561–566.
25. Challen K, Harris HJ, Julian-Reynier C, et al.; GenEd Research Group. Genetic education and nongenetic health professionals: educational providers and curricula in Europe. *Genet Med* 2005;7:302–310.
26. Burke W, Acheson L, Botkin J, et al. Genetics in primary care: a USA faculty development initiative. *Community Genet* 2002;5:138–146.
27. Laberge AM, Fryer-Edwards K, Kyler P, Lloyd-Puryear MA, Burke W. Long-term outcomes of the "Genetics in Primary Care" faculty development initiative. *Fam Med* 2009;41:266–270.
28. Hunter A, Wright P, Cappelli M, Kasaboski A, Surh L. Physician knowledge and attitudes towards molecular genetic (DNA) testing of their patients. *Clin Genet* 1998;53:447–455.
29. Harris R. Physicians and other nongeneticists strongly favor teaching genetics to medical students in the United Kingdom. *Am J Hum Genet* 1990;47:750–752.
30. Riccardi VM, Schmickel RD. ASHG activities relative to education: Human genetics as a component of medical school curricula: A report to the American society of human genetics. *Am J Hum Genet* 1988;42:639–643.
31. Burke S, Stone A, Bedward J, Thomas H, Farndon P. A "neglected part of the curriculum" or "of limited use"? Views on genetics training by nongenetics medical trainees and implications for delivery. *Genet Med* 2006;8:109–15.